

HOSPITAL AND MEDICAL FACILITIES SERIES

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Effects of GLAZING and BUILDING ORIENTATION on HOSPITAL AIR-CONDITIONING COSTS

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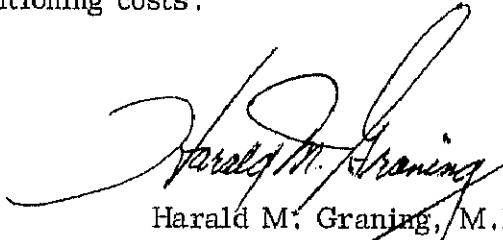
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FOREWORD

An important consideration in the planning of today's hospital is the applicability of various innovations in architecture and engineering. Of growing interest to many hospital designers are the questions relating to the recent trend in the use of large expanses of glass in the exterior wall. As with many new developments, the implications of this trend cannot be fully realized until its total effect is evaluated.

This publication is presented to indicate to those responsible for the design of hospitals some of the effects of glazing and building orientation on hospital air-conditioning costs.



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INTRODUCTION

The past decade has seen many new developments in architectural and engineering design for the construction of buildings. Many of these innovations are functionally sound and aesthetically desirable when applied with sound judgment and a thorough understanding of their implications to the total structure. However, as with most new developments, experience is required to demonstrate many of the unanticipated problems associated with their application. Among these new developments which should be considered carefully by those entrusted with planning and construction of new medical facilities is the use of large glass areas for exterior building walls in lieu of conventional wall construction.

Over the years, glazed openings have played an indispensable part in satisfying man's desire to observe his natural surroundings while maintaining a degree of protection from the elements. Also they have served as a means of providing light and ventilation. Such openings are considered of sufficient importance to man's well-being that they are a mandatory requirement for habitable areas in many building codes.

The extensive use of glass in exterior walls, however, is of comparatively recent origin. It became practical for environmental comfort only after the art of heating and cooling had progressed to its present stage, as exemplified by the modern

air-conditioning system. These modern systems not only compensate for the extremely high heat gain and loss through large glass areas, but also provide fresh air and an environment with the desired temperature and humidity.

Experience with air-conditioning has indicated that windows should not be opened indiscriminately by occupants of the building if the effectiveness of the air-conditioning system is to be maintained. As a result, the functional use of windows as a means of ventilation is fast disappearing. This is particularly true in hospitals where the control of air within and between departments is assuming more importance in the control of the spread of infective particulates and odor.

With the advances in modern artificial illumination, it is possible to provide more comfortable lighting levels for general use and certainly more efficient lighting for clinical examination and general observation of the patient than by the use of natural light provided by windows. The ability to view the exterior surroundings can be of extreme importance in the long-term care type facility and windows should not be eliminated from nursing areas of the general hospital. However, they serve no particular therapeutic purpose in diagnostic, treatment, intensive care, and nursery units.

BASIC THERMODYNAMIC PRINCIPLES

The choice of the exterior wall material, whether it be glass, masonry, or any desired combination of these, and the choice of the orientation of these walls and the configuration of the hospital within the confines of the proposed hospital site are the prerogatives of the hospital planning board and their architects. But in exercising these prerogatives, they should be aware of the effect these choices may have on the initial construction costs and the operating costs, taking into consideration the basic thermodynamic principles involved. To indicate some of the possible results of these choices, the following discussion and charts are presented.

One of the thermodynamic principles used is the heat flow through an exterior wall because of the difference in temperature on opposite sides of

the wall. The rate at which this heat flow takes place is known as the heat transmission factor. The heat transmission factor for a square foot of window glass is 1.13 BTU's per hour per degree Fahrenheit temperature difference on opposite sides of the glass. In comparison, the masonry wall used in the discussion and charts to follow was composed of 4-inch face brick, 8-inch cinder block, lath, and plaster. It has a transmission factor per square foot of 0.23 BTU's per hour per degree Fahrenheit temperature difference, approximately one-fifth that of the glass. The transmission factor for most materials and combinations of materials is available to the hospital architect. By a judicious selection of materials, he can control, within economic limits, the rate of heat transmission resulting from the difference in the outside and the inside temperatures.

The second thermodynamic principle used is the heat gain caused by exposure to the sun. There are many elements that affect the amount of heat that reaches a particular wall from the sun. Among those that the hospital designer cannot control are the time of the year and the day, the haze or clouds in the sky, and the altitude and geographical location. Among those that the designer may or may not control are the orientation of the building relative to the sun, and the amount of solar heat reflected by, transmitted directly through, and/or

absorbed by the exterior walls. The amount of solar heat transmitted directly through a particular wall depends on the opaqueness or transparency of that wall. A brick wall would keep all the solar heat from being transmitted directly through, while a single pane of clear glass will transmit directly through up to 87 percent of the solar heat. The amount of sunshine absorbed by a wall is that which has not been either reflected by or transmitted through the wall.

DESIGN CONDITIONS AND ASSUMPTIONS

The following design conditions and assumptions were used in developing the charts which follow:

1. The hospital is located at a 40° latitude and has a solar declination of 18° north on August 1 with outside temperatures of 95°F . dry bulb and 78°F . wet bulb, and inside temperatures of 80°F . dry bulb and 67°F . wet bulb.

2. All exterior glass values used on all charts, except chart 8, were calculated for single regular plate glass without any of the reduction factors associated with inside or outside shading devices, double glass, or heat absorbing glass.

3. The masonry wall used was composed of 4-inch face brick, 8-inch cinder block, lath, and plaster.

4. One ton of cooling is equal to 12,000 BTU's per hour.

5. An estimated installed cost of \$1,000 per ton of air-conditioning system was used. (To determine chart values for other per ton costs, multiply the chart value by the new ton cost and divide by 1,000.)

6. The per square foot of exterior values shown on the charts were computed by using only the heat gain or loss caused by the exterior conditions and the inside design temperatures. They do not include any of the heat gain due to people, equipment, lights, and outdoor ventilating air.

7. The estimated operating and maintenance costs of the cooling portion of the air-conditioning system were based on a one-hundred-ton system, with the compressor cooling tower and pump operating 1,000 hours, and the blower fans and circulating pump operating 3,600 hours. This cost was prorated to the per square foot requirements of the exterior walls. The estimated costs included electrical energy, electrical demand, water used by cooling tower, oiling, greasing, cleaning, and repairing.

8. The estimated maintenance cost of the masonry wall includes cleaning exterior brick (once in 35 years), repointing exterior brick (once in 35 years), and painting interior wall (once each year) with these costs prorated per year per square foot.

9. The estimated maintenance cost of regular plate glass window includes cleaning windows (4 times per year) and caulking windows (once in 16 years) prorated per year per square foot, but does not include any replacement costs of broken windows.

10. The estimated yearly cost of winter heating fuel per square foot of exterior wall is based on 5,400 degree days for design conditions of 0°F . outside and 70°F . inside for an area similar to Dayton, Ohio. It does not include any reduction in fuel requirements because of heat gain from sun shining on walls or internal heat producing factors such as people, lights, and equipment.

PER-SQUARE-FOOT COST CHARTS

Chart 1 shows a plot of the estimated installed cost (\$1,000 per ton) of the air-conditioning (cooling) system required per square foot of exterior wall for various percentages of masonry and single plate glass for four different exposures. This chart shows that the amount of air conditioning required increases with an increased percentage of glass. It also indicates that the larger the percent of glass, the more important the orientation of the wall becomes. A square foot of glass on the west requires approximately six times as much cooling as a square foot of glass on the north.

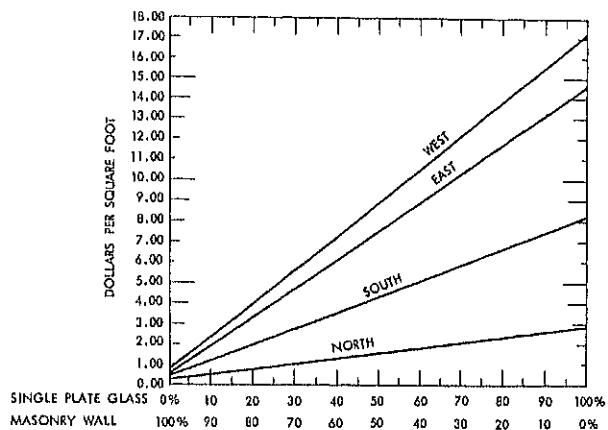


Chart 1.—Installed cost of air conditioning (cooling) required because of heat gain through the exterior wall.

Chart 2 adds the estimated costs of the exterior walls to the installed cost of the air conditioning of chart 1. The costs of the exterior walls used were \$3.60 per square foot of masonry and \$5.60 per square foot of single regular plate glass. This chart shows that paying more for an exterior wall does not always result in a reduction in associated costs. Chart 8, to be discussed later, indicates circumstances in which the spending of additional construction money may be economically justified.

Chart 3 is a plot of the estimated cost to maintain the exterior wall (inside and outside surfaces) for various percentages of masonry and single regular plate glass. The masonry wall maintenance cost includes the painting of the inside surface once a year, and cleaning and repointing exterior brick once in 35 years prorated per year. The single regular plate glass wall maintenance cost includes the cleaning of the glass four times per year, and recaulking the glass once in 16 years, prorated per year. The

costs used in the chart do not include any costs of maintaining curtains, venetian blinds, screens, or shading devices that might be used with a single regular plate glass.

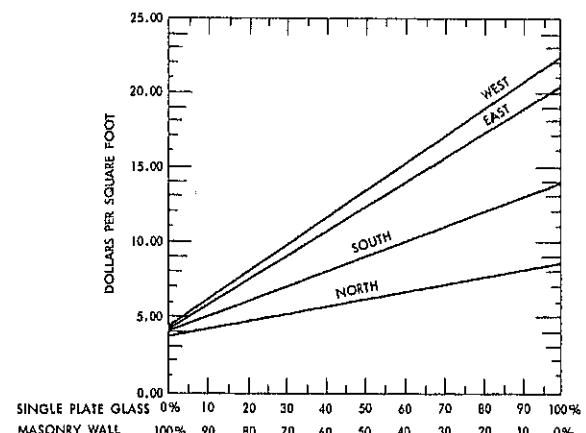


Chart 2.—Combined installed cost of exterior wall and air conditioning (cooling) required because of heat gain through the exterior wall.

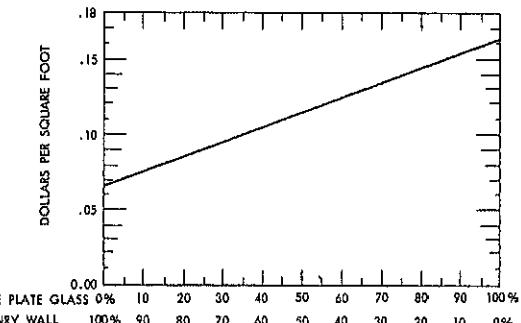


Chart 3.—Yearly cost to maintain the exterior wall.

Chart 4 is a plot of the estimated cost to operate the air-conditioning system for the cooling season per square foot of exterior wall for four different exposures. This cooling season was estimated to be 5 months and included 3,600 hours of blower fans and chilled water circulating pump operation and 1,000 hours of compressor, cooling tower fan, and pump. This chart does not include any winter operation cost of compressor and cooling tower. It shows that as the percent of glass increases the cost goes up. In addition, it shows that the cost of operation can be reduced by avoiding the large expanses of glass on the west.

Chart 5 is a plot of the estimated costs to maintain the required air-conditioning (cooling) system per square foot of exterior wall for vari-

ious percentages of masonry and single regular plate glass for four different exposures.

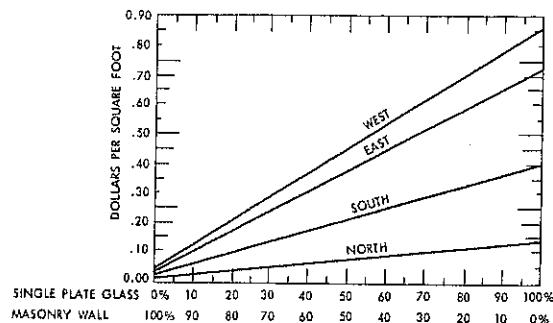


Chart 4.—Cooling season cost to operate the air-conditioning system required because of heat gain through the exterior wall.

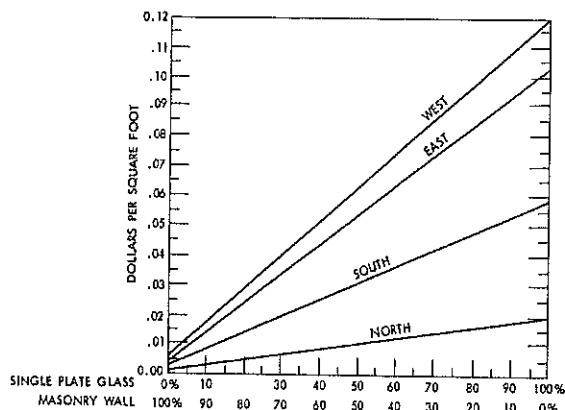


Chart 5.—Yearly cost to maintain the air conditioning (cooling) required because of heat gain through the exterior wall.

Chart 6 is a plot of the combined operation and maintenance costs per year of the air-conditioning (cooling) system required per square foot of exterior wall for various percentages of masonry and single regular plate glass for four different exposures.

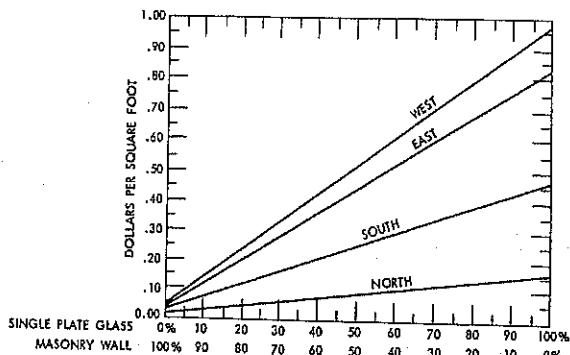


Chart 6.—Combined yearly cost to operate and maintain the air conditioning (cooling) required because of heat gain through the exterior wall.

Chart 7 is the sum of the costs represented in charts 3, 4, and 5. It is the combined yearly cost per square foot of exterior wall to maintain the exterior wall, and to operate and maintain the air-conditioning (cooling) system required by various percentages of masonry and single regular plate glass for four different exposures.

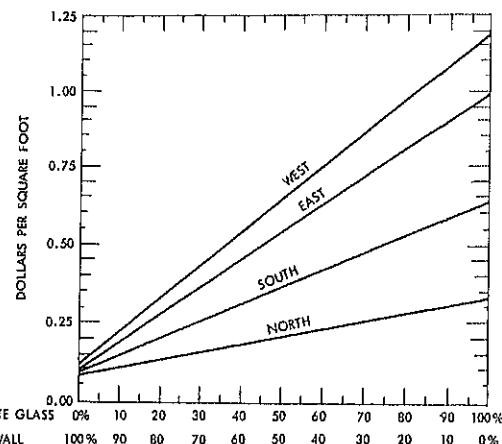


Chart 7.—Combined yearly cost to maintain the exterior wall and to operate and maintain the air conditioning (cooling) required because of heat gain through the exterior wall.

Chart 8 is a bar graph which shows the air-conditioning (cooling) requirements per square foot for several different window types, as well as a square foot of masonry, for four different exposures. The window types include: single regular plate glass, double regular plate glass, single heat absorbing glass, single regular plate glass with venetian blinds, and single regular plate glass with exterior shading screen. This chart indicates that almost any modification of a plain glass opening will reduce the solar gain through it and thereby reduce the air-conditioning requirements. It is possible in some instances, that the savings resulting from the reduction in the air-conditioning requirements could pay for the additional cost of blinds, shading screens, etc. The chart indicates this would be more likely for an east or west exposure.

Chart 9 is a plot of the solar heat gain through each square foot of single regular plate glass in an exterior wall for four different exposures on a sunny November 21st or January 21st at a 40° latitude. The horizontal dotted line on the chart at 79 BTU's is a reference line to indicate the design heat loss or the amount of heat needed to maintain a 70°F temperature in a room with a 0°F outside temperature. The chart shows that all

exposures would require about 79 BTU's of heating from a heating system prior to 8 a.m. and after 4 p.m. to maintain a 70°F. inside temperature. But between 8 a.m. and 4 p.m., the requirements to maintain a 70°F. inside temperature vary with the exposure and the time of day. For instance, at 12 noon a square foot of glass on the north would receive about 11 BTU's solar heat and would require only 68 BTU's from the heating system to maintain a 70°F. inside temperature. The glass on the east would require 22 BTU's of cooling at 9 a.m. and glass on the west would require 22 BTU's of cooling at 3 p.m. A southern exposure would require some cooling from a little after 8 a.m. to just before 4 p.m. with a maximum of 90 BTU's of cooling needed at 12 noon to maintain a 70°F. inside temperature. The masonry wall ($U=.23$) is not shown on this chart, but its design heat loss would be 16.1 BTU's with 0°F. outside and 70°F. inside for all exposures. With the masonry wall in the sun the heat required to maintain 70°F. inside would be reduced, but not enough to require cooling.

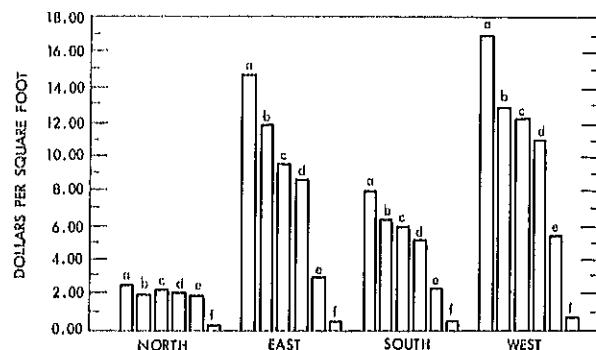


Chart 8.—Installed cost of the air conditioning (cooling) required because of heat gain through several different exterior combinations.

(a. single regular plate glass; b. double plate glass; c. single heat-absorbing plate glass; d. single regular plate glass with venetian blinds inside; e. single regular plate glass with shade screen outside; f. masonry.)

Chart 10 is a plot of the estimated yearly fuel cost of No. 6 fuel (6¢/gal.) required per square foot of exterior wall by various percent-

ages of single regular plate glass and masonry wall ($U=.23$) based on design heat loss of 0°F. outside, 70°F. inside, and 5,400 degree days. No allowance was made for any heat gain caused by the sun shining on the exterior walls on sunny days, although chart 9 shows that this heat gain could be significant when trying to maintain a 70°F. inside temperature. The estimated heating fuel costs per heating season per square foot of exterior wall shown on the chart were from 1.7 cents for a square foot of masonry wall ($U=.23$) to 8.3 cents for a square foot of single regular plate glass.

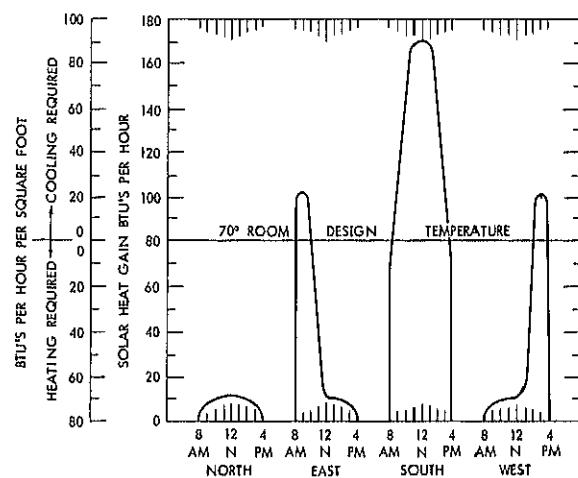


Chart 9.—Heating and/or cooling required on a sunny November 21 or January 21 at a 40° latitude because of heat gain or loss through single plate glass with 0°F. outside temperature.

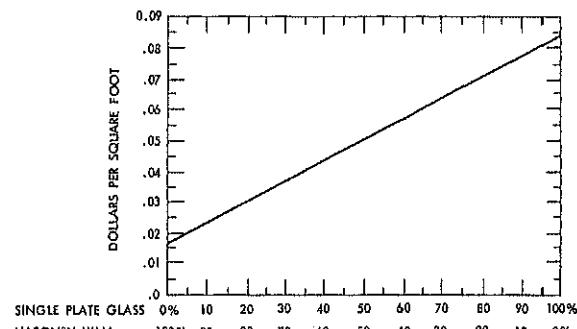


Chart 10.—Heating season cost of No. 6 fuel required because of heat loss through the exterior wall.

CHART VALUES APPLIED TO TYPICAL HOSPITAL

The preceding discussion and charts 1 to 10 are concerned with some of the costs related to a square foot of exterior wall for various percentages of masonry and/or glass for four different exposures. Figures 1 and 2, which follow,

show the effect of the choice of exterior wall material and orientation on costs for a typical hospital. Figures 1 and 2 are for the same sized hospital—200 feet on the long sides, 50 on the short sides, and 50 feet high.

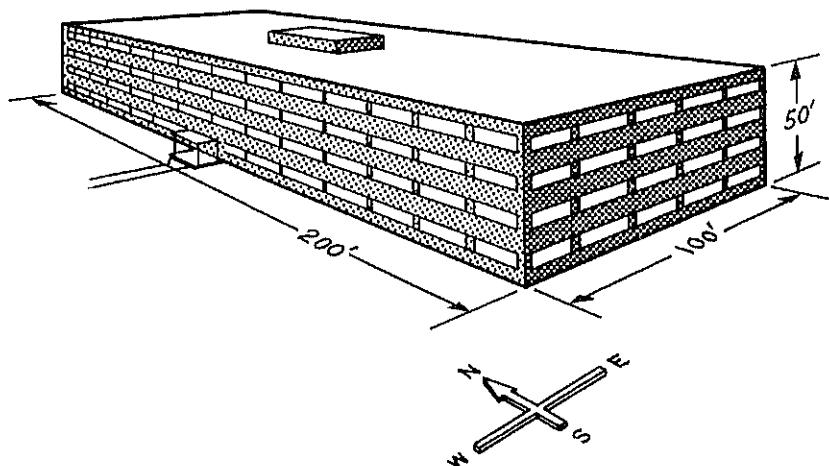
Figure 1 shows the hospital with the long sides east and west and the short sides north and south. The first cost shown is \$124,474 (\$1,000 per ton) which is the estimated installed cost of the air-conditioning (cooling) system required because of the heat gain through the exterior walls consisting of 30 percent single regular plate glass and 70 percent masonry ($U=.23$). The second cost shown is \$7,056 which is the estimated cost per year to operate and maintain this air-conditioning (cooling) system.

Figure 1 also shows the estimated costs when the 30 percent glass portion of the wall was increased to 40 percent and the 70 percent masonry decreased to 60 percent. The installed cost of air conditioning required because of the exterior wall heat gain is increased to \$160,092 which is

\$35,618 more than it was with a 30 percent glass exterior wall. The estimated operation and maintenance cost per year was increased to \$9,075 which is \$2,019 more than it was with 30 percent glass.

The costs given in figure 1 show that if the quantity of single plate glass installed in the exterior wall is increased from 30 percent of the total wall surface to 40 percent, a 28 percent increase in the quantity of air conditioning could be required because of the heat gain through the additional glass surface; a 28 percent increase in the annual cost of operation and maintenance of this system could also result.

Figure 2 shows the same size hospital as in figure 1 except the orientation, or exposure, is



EXTERIOR WALLS : 30% SINGLE REGULAR PLATE GLASS
70% MASONRY

AIR CONDITIONING :	INSTALLED COST	\$124,474
	OPER. AND MAINT. PER YEAR	7,056

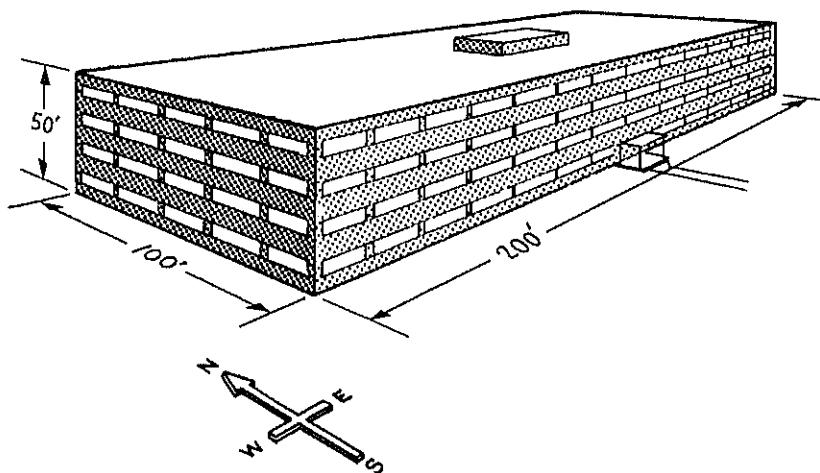
EXTERIOR WALLS : 40% SINGLE REGULAR PLATE GLASS
60% MASONRY

AIR CONDITIONING :	INSTALLED COST	\$160,092
	OPER. AND MAINT. PER YEAR	9,075

Figure 1.—Hospital oriented with long sides east and west.

changed so that the long sides are north and south and the short sides are east and west. The first cost shown in figure 2 is \$91,118, the estimated installed cost of the air-conditioning (cooling) system required because of the heat gain through the exterior walls consisting of 30 percent single regular plate glass and 70 percent masonry ($U=.23$). The second cost shown is \$5,165 which is the estimated cost per year to operate and maintain this air-conditioning system.

Figure 2 also shows the estimated costs when the 30 percent glass portion of the walls was increased to 40 percent and the 70 percent masonry decreased to 60 percent. The installed cost of the air-conditioning (cooling) system is increased to \$116,734 which is \$25,616 more than it was when the exterior wall was 30 percent glass. The estimated operation and maintenance per year was increased to \$6,617 which is \$1,452 more than it was with a 30 percent glass exterior.



EXTERIOR WALLS: 30% SINGLE REGULAR PLATE GLASS
70% MASONRY

AIR CONDITIONING:	INSTALLED COST	\$ 91,118
	OPER. AND MAINT. PER YEAR	5,165

EXTERIOR WALLS: 40% SINGLE REGULAR PLATE GLASS
60% MASONRY

AIR CONDITIONING:	INSTALLED COST	\$ 116,734
	OPER. AND MAINT. PER YEAR	6,617

Figure 2.—Hospital oriented with long sides north and south.

COMPARISON OF FIGURES 1 AND 2

A comparison of the costs in figures 1 and 2 shows that the estimated installed costs of the air conditioning required by the exterior walls with 30 percent single regular plate glass vary from \$124,474 with long sides east and west to \$91,118 with the long sides north and south. The orientation in this instance makes a \$33,364 difference.

A comparison of the costs noted in figures 1 and 2 shows that installed costs of the air condition-

ing required by the 40 percent single regular plate glass exterior walls vary from \$160,092 with the long sides east and west to \$116,734 with the long sides north and south. The orientation of the hospital in this instance makes a difference of \$43,358.

A comparison of the operation and maintenance per year costs in figures 1 and 2 shows that costs for the 30 percent single regular plate

glass exterior walls vary from \$7,056 for long sides east and west to \$5,165 with the long sides north and south. This is a difference of \$1,891 for each year the system operates.

The comparison of the operation and maintenance costs in figures 1 and 2 for the 40 percent single regular plate glass exterior walls shows that costs vary from \$9,075 with long sides east and west to \$6,617 when the long sides are north and south. This is a difference of \$2,458 for each year the system operates.

All the preceding discussion, charts, and figures are presented to make hospital owners and hospital designers more aware of the effect the choice of the exterior wall materials and the orientation of those walls can have on hospital construction and operating costs. It is also intended to show that if glass is to be used extensively as an outside wall material, careful consideration should be given to the orientation of the building and to the use of shading devices or heat absorbent types of glass.

SELECTED BIBLIOGRAPHY

1. American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc. ASHRAE Guide and Data Book 1961, ch. 23, pp. 383-420. 1961.
2. Building Research Institute. National Academy of Sciences, National Research Council. Windows and Glass in the Exterior of Buildings, Publication No. 478. Washington 25, D.C. 176 pp. 1957.
3. Economics of LOF's Glass-Walled Skyscraper. Progressive Architecture, XLII(5):166-74. May 1961.
4. Means, R. S. Building Construction Cost Data 1962. 20th Annual Edition. Robert Snow Means Co., Duxbury, Mass. 138 pp. 1962.
5. Olgyay, Aladar and Olgyay, Victor. Solar Control and Shading Devices. Princeton University Press, Princeton, N.J. 201 pp. 1957.
6. Parmelee, G. V. and Aubele, W. W. Overall Coefficient for Flat Glass Under National Weather Conditions. No. 1351, ASHRAE Transactions. 55:39-60. 1949.
7. Parmelee, G. V. and Aubele, W. W. Heat Flow Through Unshaded Glass. No. 1399, ASHRAE Transactions. 56:371-98. 1950.

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